

## **Appendix 8**

### **Habitat Suitability Criteria**

This appendix describes the details of determining habitat suitability criteria for the selected species. These criteria were used to evaluate the habitat quality in the areas mapped during this project. They were established based on empirical data (for adult resident fish in summer) as well as literature surveys (spawning life stage). For each species we identified criteria specifying not-suitable, suitable and optimal habitat. Habitat models were for longnose dace, blacknose dace, common shiner, fallfish and white sucker, slimy sculpin, Atlantic salmon, brook trout, mussels and odonates.

### **Empirical data based model.**

The empirical set of criteria for rearing and growth (R&G) season had been developed from habitat use data collected in earlier studies. For resident 1+ and older, longnose dace, blacknose dace, common shiner, fallfish, white sucker, slimy sculpin, Atlantic salmon and brook trout we analyzed fish habitat data from several locations. These data were collected on the Pomperaug River (196 grids), Eightmile River (345 grids) and Fenton River (506 grids) in Connecticut as well as 455 grids collected from Stony Clove (269), Roundout River (106), Trout Brook (24), Spring Brook (24), Stewart Brook (16) and Willowemoc (16) in New York. For each species we used only data from rivers where they occurred in significant numbers (more than 5 individuals captured). We used a multivariate statistical model (logistic regression) to compute the habitat selection criteria for adult resident fish species and Atlantic salmon. For mussels and odonates we followed a similar procedure; however the data stems from 228 quadrates sampled in the Souhegan River (see Appendix 7). At each grid and quadrate the physical attributes of the HMU in which it was located were recorded together with the number of individuals and species captured.

To calculate the response functions for the species above, we described each grid that was sampled during the survey in terms of the same environmental characteristics used to develop the habitat database, as well as by the species presence and abundance. The environmental attributes were independent variables and the species were dependent variables in regression models describing habitat preference. We employed a stepwise forward logistic regression model (using SPSS) to identify the characteristics of habitat that is used versus habitat that is not used by each fish species. The model uses likelihood ratios to determine which parameters should be included in the following regression formula:

$$R=e^{-z}$$

where:

- $e$  = natural log base
- $z$  =  $b_1 \cdot x_1 + b_2 \cdot x_2 + \dots + b_n \cdot x_n + a$
- $x_{1..n}$  = significant physical variables
- $b_{1..n}$  = regression coefficients
- $a$  = constant

We established the  $b$  coefficients using an iterative process. The  $b$  coefficients represent how the attributes influence the dependent variable in the data set. This mathematical formula is based on proportions of occupied/non-occupied areas observed during the survey and do

not capture all the possible circumstances or represent mechanisms of fish behavior. Furthermore, fish presence is due largely in part to a combination of environmental factors; interpreting the influence of individual parameters in the formula is therefore somewhat limited in applicability.

To distinguish suitable habitat, we used binary dependent variables indicating presence and absence and, in a second model, high and low abundances. The fish and invertebrate data was separated to low and high abundance classes. The cut off value was calculated from observed abundances per grid and was different for each species depending on their behavior (solitary, vs. gregarious) and size. For blacknose dace and white sucker three or more fish indicated high abundance. For fallfish, common shiner, longnose dace and tessellated darter as well as for mussels and odonates two or more individuals were needed. For brook trout, the presence of more than one indicated high abundance. We used all the available data for the presence model, and for the abundance, we used only data from grids in which fish were caught. From the output of the logistic regression function, we obtained two important types of information: the environmental attributes that significantly correspond with species presence and abundance and the regression coefficients b-values. The b-values indicate the strength and direction (+ or -) of the association between each habitat attribute and fish presence and level of abundance.

In a subsequent step we determined the predictive strength of the model as well as identified thresholds between predictions for suitable and not suitable habitat by comparing probabilities of fish presence and high abundance for each grid and actual observations. The following procedure was used:

For each mesohabitat mapped during the biological survey, we calculated the probability of fish presence using computed regression equations and the following formula:

$$p = \frac{e^z}{(1+e^z)}$$

Where:

- p = probability of presence/high abundance
- e = constant
- $z = b_1 \cdot x_1 + b_2 \cdot x_2 + \dots + b_n \cdot x_n + a$
- $x_{1..n}$  = significant physical variables
- $b_{1..n}$  = regression coefficients
- a = constant

We calculated the probability of presence and of high abundance for every species. The observed presence and abundance at each grid was associated with the probability for the HMU where the grid was located. We created a relative operating characteristic (ROC) curve for presence and abundance predictions (Metz, 1978). The curve examines the discrimination performance of the model over a range of threshold levels, by plotting proportion of grids correctly predicted to be occupied (sensitivity or true positive rate), and the proportion of grids incorrectly predicted to be occupied (false positive rate). The area under the ROC curve

defines the discrimination capacity of the model based on Mann-Whitney statistics (Pearce & Ferrier 2000). The inflection points on the ROC curve allow one to define the probability (Pt) that has the highest true positive rate and lowest false positive rate and therefore best separation of occupied and not occupied areas. Separate Pt values are selected for the presence and abundance models. In the following assessment the habitats with a probability of presence greater than Pt were classified as suitable. The suitable habitats with a probability of high abundance greater than selected Pt are deemed optimal. The areas under the curve and Pt values were selected and presented in the results section together with a list of significant parameters and B-values for both the presence and abundance models. The model was then applied to the data from the mapping survey to identify suitable and optimal habitat areas.

For the young-of-the-year (YOY) fish life stage habitat, which consists only of shallow margins, empirical criteria developed on the Quinebaug River were applied. Areas designated as shallow margins had an average depth of 12 cm (SD = 6 cm), and an average velocity of 15 cm.s<sup>-1</sup> (SD = 11). Substrate in these areas was generally small, ranging from sand to meso-lithal. Shallow margins are an attribute of a HMU and are mapped either as present or abundant. HMUs with abundant shallow margins were considered optimal.

### **Literature based habitat suitability criteria**

Due to the lack of empirical data for generic resident adult fish (GRAF) and special interest fish and invertebrates (SIFI) spawning habitat suitability, a literature-based spawning habitat model was developed based on four habitat attributes. The spawning requirements of GRAF species and two SIFI species (Atlantic salmon and American shad) with regard to these four habitat attributes: depth, velocity, choriotope (substrate type), and HMU type, were researched. Criteria, values, and ranges were selected for each attribute that was indicative of suitable spawning habitat for a selected species. A spawning model was then created that would identify suitable spawning habitats for each species based on the presence of selected habitat attributes that met the requirements of a particular species.

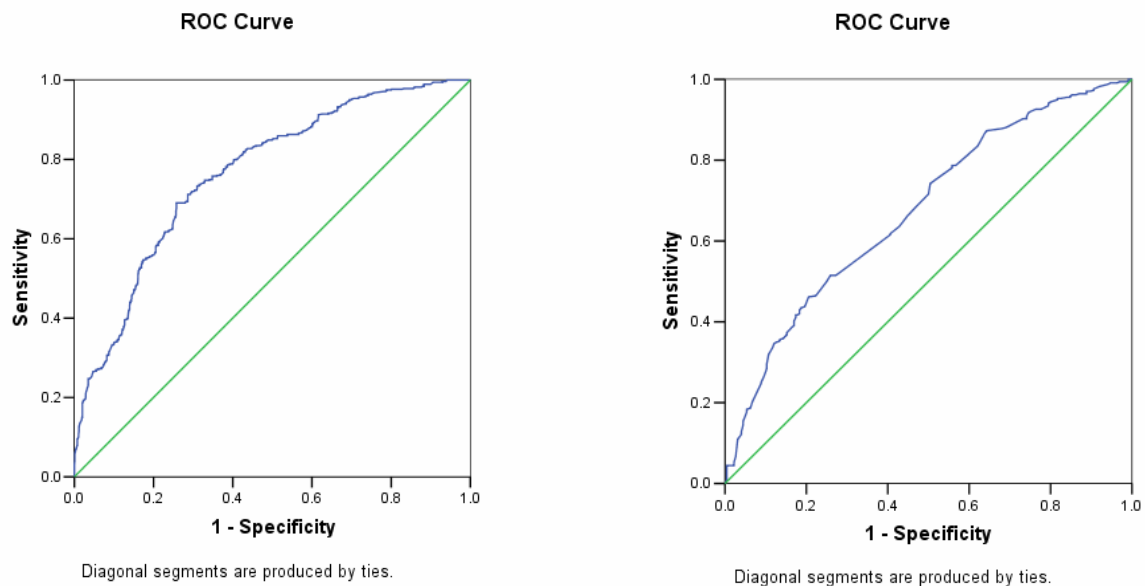
To determine suitability for a discrete HMU as defined by hydraulics, the HMU's depth and velocity distribution, choriotope distribution, and HMU type were compared to the ranges specified in the literature. With regard to HMU type, a discrete HMU is considered acceptable if its type is often associated with the other attributes of interest to the fauna. For example, a backwater was not considered to be an acceptable HMU for spawning by a species that uses fast-water areas. With regard to hydraulic measurements (7 for depth, 7 for velocity and 7 choriotope descriptions) the unit was considered to have acceptable ranges for the target fauna if at least one of the measured/mapped values (e.g., depth) was within selected limits.

Generally we presume that all the selected attributes need to be in acceptable ranges for the discrete HMU to be optimal and at least three are necessary to provide suitable habitat. However, adjustments were made to the model for individual species, for which specific habitat attributes were critical to assure suitable spawning habitat. For instance, Atlantic salmon was determined to be dependent upon microlithal (gravel) choriotope for the excavation of redds during spawning. Any HMU that did not meet the choriotope criteria for Atlantic salmon was automatically considered unsuitable. In the case of American shad it was determined that this species was most dependent upon depth and water velocity conditions for suitable spawning habitat. These two attributes had to meet the criteria for an HMU to be

considered suitable for shad spawning. Because of this species strong dependence upon these two factors, HMU were considered suitable having met only these two criteria, and optimal if they met three or more of the four criteria. Backwater mesohabitats were considered unsuitable for all species requiring flowing water for spawning. By applying this model to our previously mapped mesohabitats, spawning suitability maps could be created for GRAF, Atlantic salmon, and American shad.

## Results

Table 1 represents attributes of both models for blacknose dace established from 1504 grids from all rivers including 562 grids where blacknose dace was captured and 338 grids with high abundance of this species. The presence model consists of a high number of habitat attributes that significantly correspond with observed fish. They describe swiftly flowing but shallow HMUs such as riffles and glides as well as sidearms. Although boulder cover correlates positively with presence of this species, rapid HMUs seem to be out of their range. The model also indicates more affinity to finer substrate and undercut banks. We did not find many blacknose dace in areas with submerged vegetation and with shallow margins. The abundance model describes similar shallow habitats but with lower velocities. Figure 1 presents ROC curves for both models.



**Figure 1: ROC curve for the presence (left) and abundance (right) models indicating the accuracy of predictions of blacknose dace. Sensitivity describes true positive rate and 1-Specificity false positive rate.**

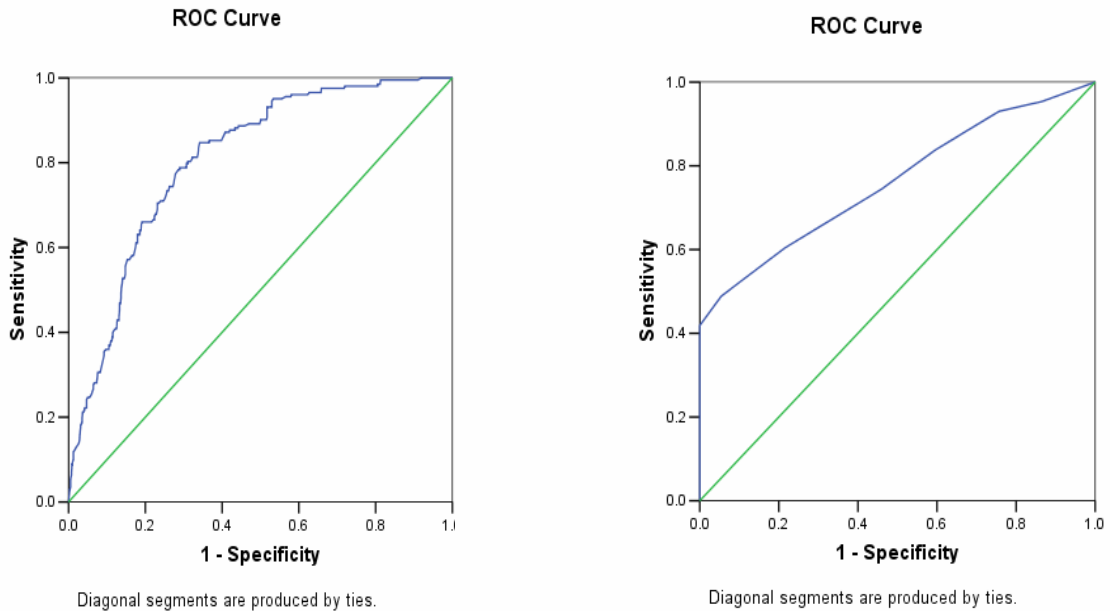
**Table 1: Physical attributes correlating with presence and high abundance of blacknose dace. The Area Under ROC curve is a measure of discrimination capacity of the model (0-1). Selected cut-off indicates the probability separating un-suitable, suitable and optimal habitats. ‘b’ represents regression coefficients of the logistic regression model.**

<b>Blacknose dace</b>			
<b>Presence Model</b>		<b>Abundance Model</b>	
Area Under ROC curve	0.76	Area Under ROC curve	0.68
Selected cut-off (Pt)	0.35	Selected cut-off (Pt)	0.57
<b>Variables in the Equation</b>	<b>b</b>	<b>Variables in the Equation</b>	<b>b</b>
Boulders	0.317	Backwater	-1.557
Submerged Vegetation	-0.881	Glide	0.943
Undercut Banks	0.217	Depth 0-25 cm	0.408
Shallow Margins	-0.222	Depth 50-75 cm	-3.112
Glide	0.403	Current Velocity 0-15 cm/s	0.982
Rapids	-1.866		
Riffle	0.494		
Sidearm	0.918		
Depth 50-75 cm	-1.152		
Depth 100-125 cm	-7.380		
Current Velocity 15-30 cm/s	0.651		
Current Velocity 30-45 cm/s	1.330		
Current Velocity 60-75 cm/s	3.219		
Macrolithal	-0.557		
Megalithal	-1.855		
Psammal	0.948		
Sapropel	-14.746		
Constant	-0.949		

Table 2 represents attributes of both models for longnose dace established from 1002 grids including 203 grids where longnose dace was captured and 166 grids with high abundance of this species. The data from the Fenton River was not used because this river is outside of the zoogeographic range of this species. The presence model consists of a number of habitat attributes that describe fast flowing shallow HMUs such as riffles and ruffles. The model also indicates more affinity to finer substrate as well as large substrate. The abundance model also describes riffle habitats, but with lower velocities. Figure 2 presents ROC curves for both models.

**Table 2: Physical attributes correlating with presence and high abundance of longnose dace. The Area Under ROC curve is a measure of the discrimination capacity of the model. Selected cut-off indicates the probability separating un-suitable, suitable and optimal habitats. ‘b’ represents regression coefficients of logistic regression model.**

<b>Longnose dace</b>			
<b>Presence Model</b>		<b>Abundance Model</b>	
Area Under ROC curve	0.86	Area Under ROC curve	0.76
Selected cut-off (Pt)	0.1	Selected cut-off (Pt)	0.5
<b>Variables in the Equation</b>	<b>b</b>	<b>Variables in the Equation</b>	<b>b</b>
Riprap	0.828	Riffle	2.336
Overhanging Vegetation	-0.433	Current Velocity 0-15 cm/s	2.507
Riffle	2.342	Constant	-2.192
Ruffle	1.667		
Depth 0-25 cm	1.963		
Current Velocity 0-15 cm/s	1.821		
Current Velocity 15-30 cm/s	1.435		
Current Velocity 75-90 cm/s	5.065		
Akal	3.320		
Megalithal	1.925		
Constant	-6.273		



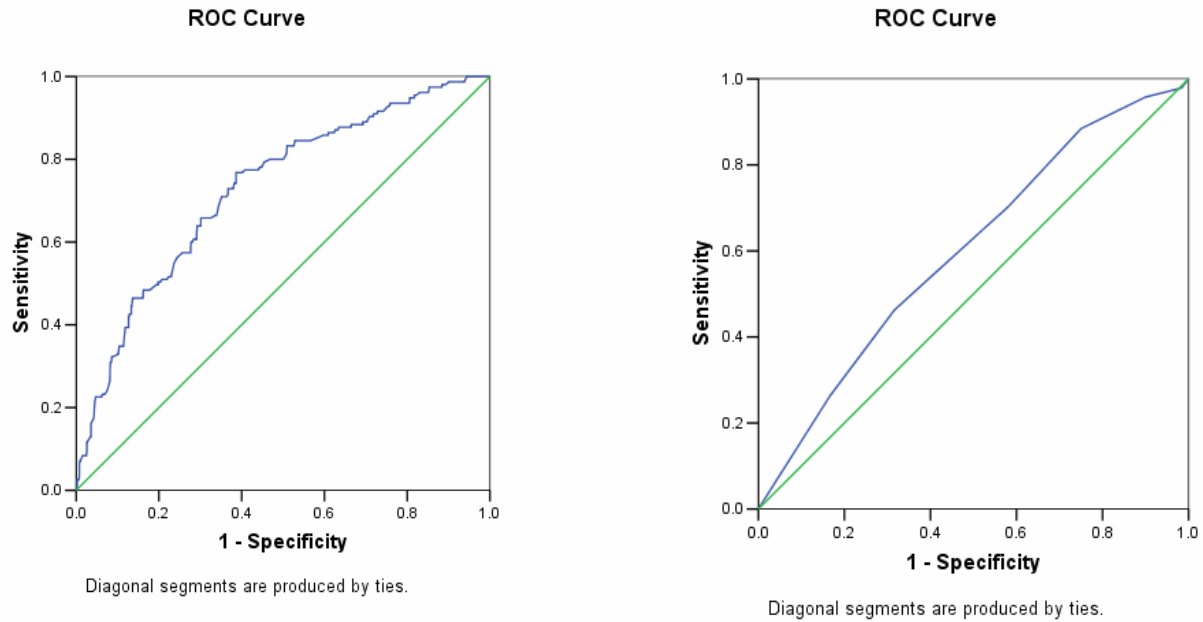
**Figure 2: ROC curve for the presence (left) and abundance (right) models indicating accuracy of predictions of longnose dace. Sensitivity describes true positive rate and 1-Specificity false positive rate.**

Table 3 represents attributes of both models for fallfish established from 1048 grids including 155 grids where fallfish was captured and 95 grids with high abundance of this species. The data from New York streams was not used because this species has not been caught there. The presence model consists of a number of habitat attributes that describe fast flowing HMUs with shallow margins. The model also indicates more affinity to finer substrate. The abundance model describes a negative correlation with small cobble. Figure 3 presents ROC curves for both models.



**Table 3: Physical attributes correlating with presence and high abundance of fallfish. The Area Under ROC curve is a measure of the discrimination capacity of the model. Selected cut-off indicates the probability separating un-suitable, suitable and optimal habitats. ‘b’ represents regression coefficients of logistic regression model.**

<b>Fallfish</b>			
<b>Presence Model</b>		<b>Abundance Model</b>	
Area Under ROC curve	0.73	Area Under ROC curve	0.6
Selected cut-off (Pt)	0.14	Selected cut-off (Pt)	0.65
<b>Variables in the Equation</b>	<b>b</b>	<b>Variables in the Equation</b>	<b>b</b>
Riprap	0.495	Mesolithal	-1.630
Submerged Vegetation	-0.581	Constant	0.930
Shallow Margins	0.305		
Glide	-1.107		
Depth 25-50cm	0.988		
Current Velocity 0-15 cm/s	-0.986		
Current Velocity 60-75 cm/s	-8.896		
Column Velocity 90-105 cm/s	11.888		
Akal	2.867		
Megalithal	1.401		
Pelal	2.346		
Constant	-2.011		

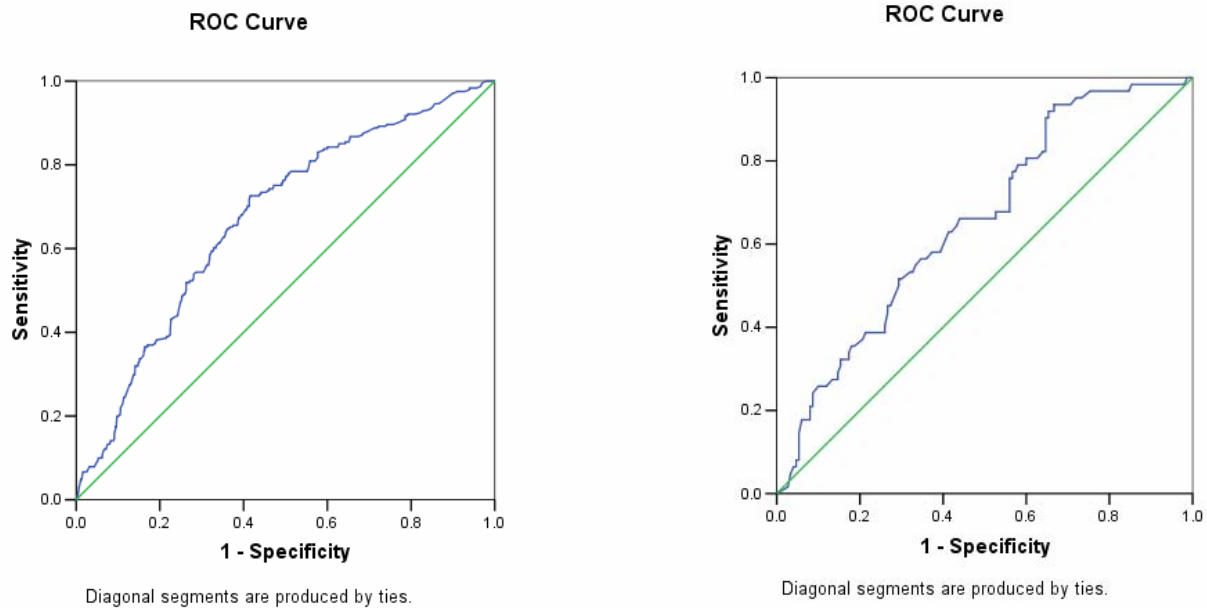


**Figure 3: ROC curve for the presence (left) and abundance (right) models indicating accuracy of predictions of fallfish. Sensitivity describes true positive rate and 1-Specificity false positive rate.**

Table 4 represents attributes of both models for white sucker established from 1504 grids including 241 grids where white sucker was captured and 62 grids with high abundance of this species. The presence model indicates affinity to finer substrate and HMUs deeper than 25 cm. The abundance model describes a negative correlation with undercut banks and an increasing Froude number. Because the Froude number reflects the proportion of riffles versus pools (Fr is generally  $<0.2$  in pool habitat and  $>0.4$  in riffle habitat; Jowett 1993), this results in a low affinity of this fish with riffle habitats. Figure 4 presents ROC curves for both models.

**Table 4: Physical attributes correlating with presence and high abundance of white sucker. The Area Under ROC curve is a measure of the discrimination capacity of the model. Selected cut-off indicates the probability separating un-suitable, suitable and optimal habitats. ‘b’ represents regression coefficients of logistic regression model.**

White sucker			
Presence Model		Abundance Model	
Area Under ROC curve	0.67	Area Under ROC curve	0.65
Selected cut-off (Pt)	0.16	Selected cut-off (Pt)	0.33
Variables in the Equation	b	Variables in the Equation	b
Akal	1.359	Undercut Banks	-0.500
Mesolithal	0.936	Average Froude	-0.438
Microlithal	2.135		
Psammal	1.951		
Depth 0-25cm	-0.798		
Constant	-2.279		

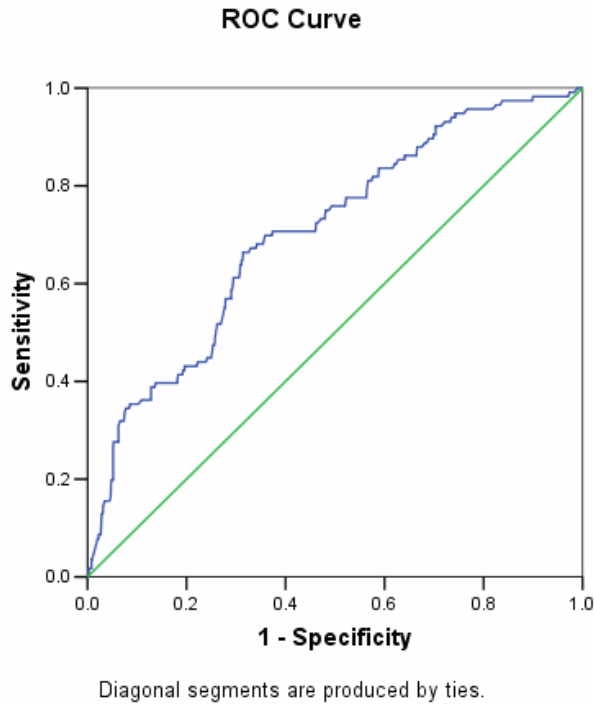


**Figure 4: ROC curve for the presence (left) and abundance (right) models indicating accuracy of predictions of white sucker. Sensitivity describes true positive rate and 1-Specificity false positive rate.**

Table 5 represents attributes of the presence model for common shiner established from 851 grids including 99 grids where common shiner was captured and no grids with a high abundance of this species. Only data from the Fenton and Eightmile Rivers had a sufficient number of observations to be used in this model. The presence model indicates affinity with deeper run HMUs with shallow margins and woody debris. Figure 5 presents ROC curves for presence model.

**Table 5: Physical attributes correlating with presence and high abundance of common shiner. The Area Under ROC curve is a measure of the discrimination capacity of the model. Selected cut-off indicates the probability separating un-suitable, suitable and optimal habitats. ‘b’ represents regression coefficients of logistic regression model.**

<b>Common shiner</b>	
<b>Presence Model</b>	
Area under ROC curve	0.70
Selected cut-off (Pt)	0.10
<b>Variables in the Equation</b>	<b>b</b>
Submerged Vegetation	-0.478
Woody Debris	0.253
Shallow Margins	0.297
Run	0.516
Depth 0-25 cm	-0.921
Megalithal	2.018
Microlithal	1.358
Constant	-2.758

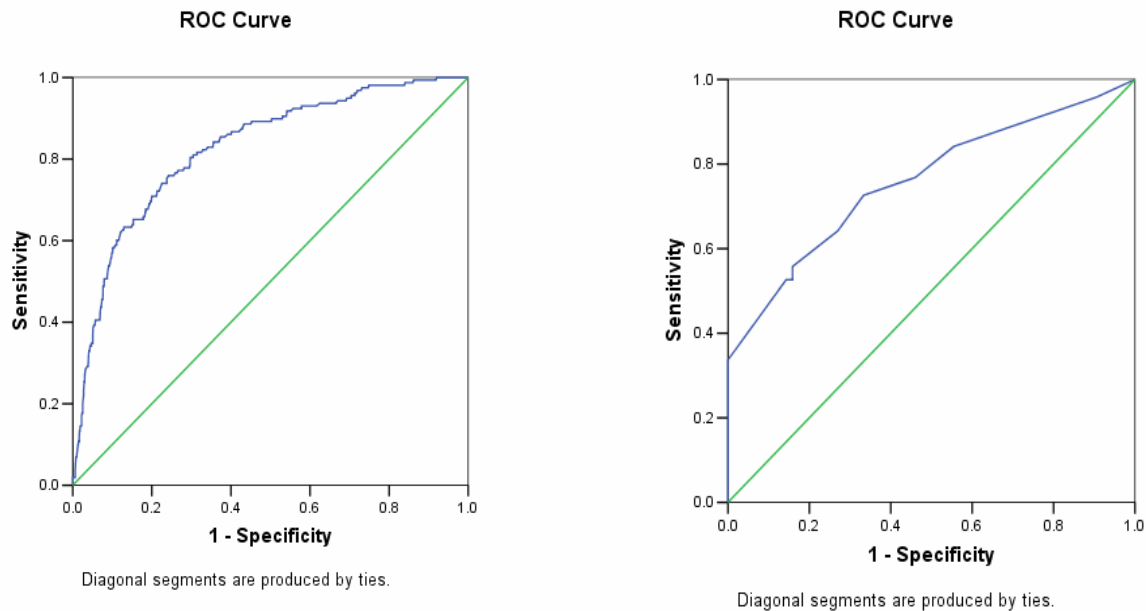


**Figure 5: ROC curve for the presence model indicating accuracy of predictions of common shiner. Sensitivity describes true positive rate and 1-Specificity false positive rate.**

Table 6 represents attributes of both models for brook trout established from 1504 grids including 158 grids where brook trout was captured and 95 grids with high abundance of this species. The presence model consists of a number of habitat attributes that describe shaded, moderate to fast flowing pool habitat with shallow areas and larger substrate. The abundance model shows correlation with riffles and woody debris. Figure 6 presents ROC curves for both models.

**Table 6: Physical attributes correlating with presence and high abundance of brook trout. The Area Under ROC curve is a measure of the discrimination capacity of the model. Selected cut-off indicates the probability separating un-suitable, suitable and optimal habitats. ‘b’ represents regression coefficients of logistic regression model.**

<b>Brook trout</b>			
<b>Presence Model</b>		<b>Abundance Model</b>	
Area under ROC curve	0.82	Area under ROC curve	0.76
Selected cut-off (Pt)	0.09	Selected cut-off (Pt)	0.52
<b>Variables in the Equation</b>	<b>b</b>	<b>Variables in the Equation</b>	<b>b</b>
Overhanging Vegetation	-0.239	Woody Debris	1.305
Submerged Vegetation	0.424	Shallow Margins	-0.600
Canopy Shading	0.380	Riffle	1.113
Plunge pool	2.899		
Pool	0.928		
Riffle	-0.607		
Ruffle	-1.064		
Depth 0-25cm	1.017		
Column Velocity 45-60 cm/s	-2.463		
Akal	-8.630		
Macrolithal	1.803		
Pelal	-5.932		
Psammal	-4.389		
Constant	-3.010		



**Figure 6: ROC curve for the presence (left) and abundance (right) models indicating accuracy of predictions of brook trout. Sensitivity describes true positive rate and 1-Specificity false positive rate.**

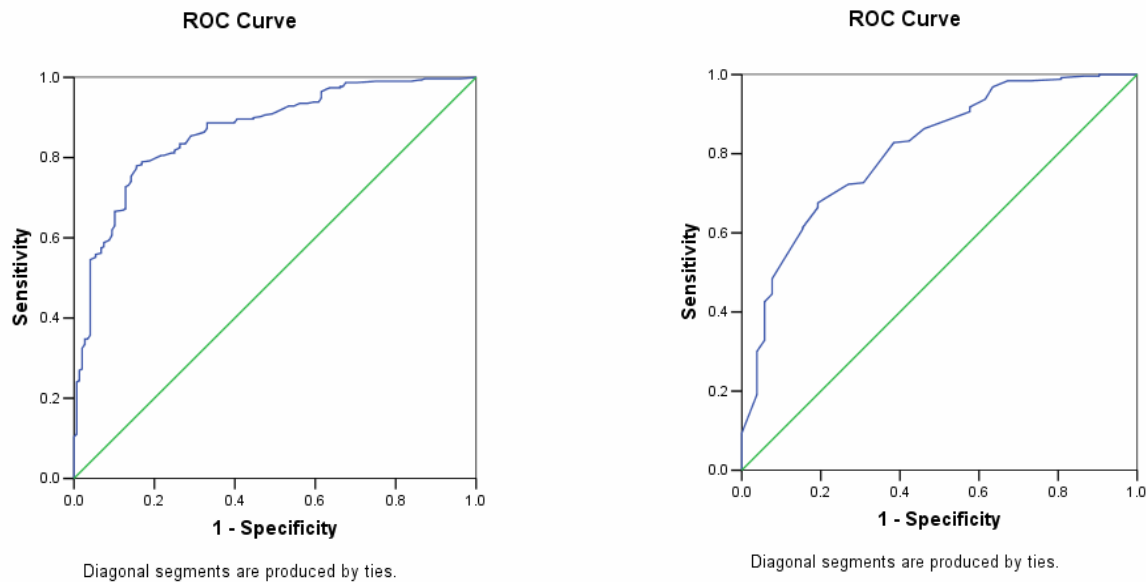
Table 7 represents attributes of both models for slimy sculpin established from 1504 grids including 308 grids where slimy sculpin was captured and 256 grids with a high abundance of this species. The presence model consists of a number of habitat attributes that describe shaded, moderate to fast flowing pool habitat with shallow areas and high affinities to substrate ranging from gravel to boulders. The abundance model shows correlation with submerged vegetation and a negative correlation with bedrock, moderate depth and velocity. The Figure 7 presents ROC curves for both models.

Table 8 represents attributes of both models for American eel established from 345 grids including 116 grids where American eel was captured and 38 grids with a high abundance of this species. We used the data from the Eightmile River, because only this river had a substantial number of this species captured. The presence model indicates an affinity to pool habitat. The abundance model shows a correlation with boulder cover and a negative correlation with sand. Figure 8 presents ROC curves for both models.

**Table 7: Physical attributes correlating with presence and high abundance of slimy sculpin. The Area Under ROC curve is a measure of the discrimination capacity of the model. Selected cut-off indicates the probability separating un-suitable, suitable and optimal habitats. ‘b’ represents regression coefficients of logistic regression model.**

<b>Slimy sculpin</b>			
<b>Presence Model</b>		<b>Abundance Model</b>	
Area under ROC curve	0.94	Area under ROC curve	0.81
Selected cut-off (Pt)	0.25	Selected cut-off (Pt)	0.74
<b>Variables in the Equation</b>	<b>b</b>	<b>Variables in the Equation</b>	<b>b</b>
Boulders	-0.951	Submerged Vegetation	2.508
Riprap	0.582	Depth 25-50cm	-1.657
Overhanging Vegetation	-0.818	Current Velocity 60-75 cm/s	-3.837
Submerged Vegetation	1.163	Megalithal	-1.65
Canopy Shading	0.541	Constant	1.99
Woody Debris	-0.664		
Backwater	2.421		
Plunge pool	3.371		
Pool	2.133		
Riffle	-1.003		
Ruffle	-1.437		
Depth 0-25 cm	1.439		
Current Velocity 0-15	-2.671		
Akal	26.249		
Macrolithal	28.420		
Megalithal	26.608		
Mesolithal	27.083		
Microlithal	22.230		
Constant	-26.842		

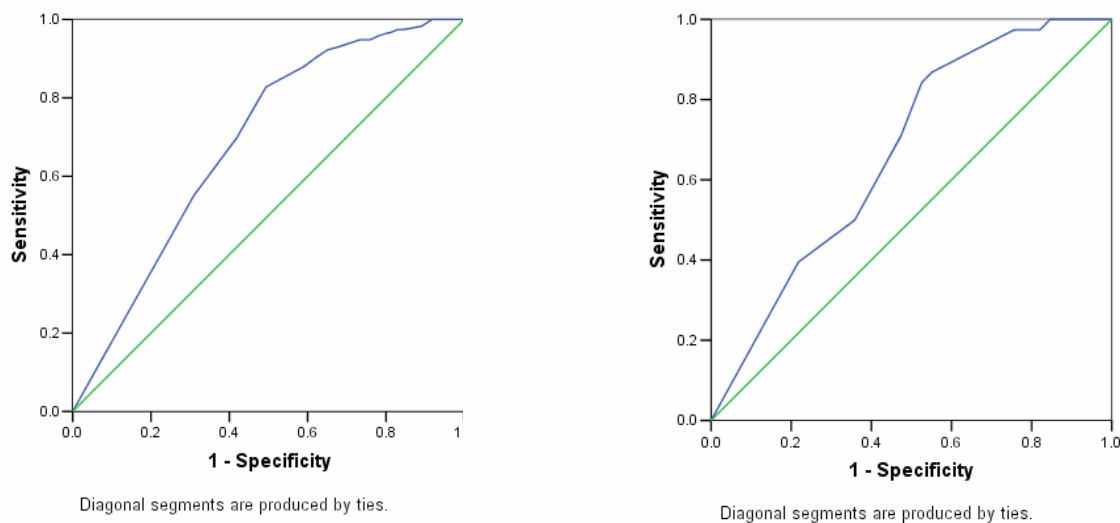




**Figure 7: ROC curve for the presence (left) and abundance (right) models indicating accuracy of predictions of slimy sculpin. Sensitivity describes true positive rate and 1-Specificity false positive rate.**

**Table 8: Physical attributes correlating with presence and high abundance of American eel. The Area Under ROC curve is a measure of the discrimination capacity of the model. Selected cut-off indicates the probability separating un-suitable, suitable and optimal habitats. ‘b’ represents regression coefficients of logistic regression model.**

<b>American eel</b>			
<b>Presence Model</b>		<b>Abundance Model</b>	
Area under ROC curve	0.80	Area under ROC curve	0.67
Selected cut-off (Pt)	0.38	Selected cut-off (Pt)	0.31
<b>Variables in the Equation</b>	<b>b</b>	<b>Variables in the Equation</b>	<b>b</b>
Pool	2.712	Boulders	0.598
Pelal	3.345	Psammal	-3.911
Psammal	-5.080	Constant	-1.164

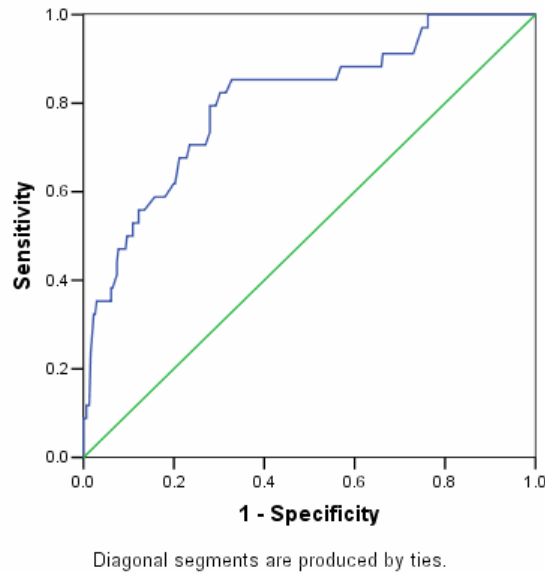


**Figure 8: ROC curve for the presence (left) and abundance (right) models indicating accuracy of predictions of American eel. Sensitivity describes true positive rate and 1-Specificity false positive rate.**

Table 9 represents attributes of both models for Atlantic salmon established from 345 grids including 34 grids where Atlantic salmon was captured and no grids with high abundance of this species. We used the data from the Eightmile River, because only this river had a sufficient number of this species captured. The presence model indicates affinity to riffle habitat with gravel and high Froude numbers (i.e. riffle habitat). The Figure 9 presents ROC curves for presence model.

**Table 9: Physical attributes correlating with presence and high abundance of slimy sculpin. The Area Under ROC curve is a measure of the discrimination capacity of the model. Selected cut-off indicates the probability separating un-suitable, suitable and optimal habitats. ‘b’ represents regression coefficients of logistic regression model.**

<b>Atlantic salmon</b>	
<b>Presence Model</b>	
Area under ROC curve	0.69
Selected cut-off (Pt)	0.24
<b>Variables in the Equation</b>	<b>b</b>
Riffle	2.034
Microlithal	2.712
Average Froude	3.345
Constant	-5.080

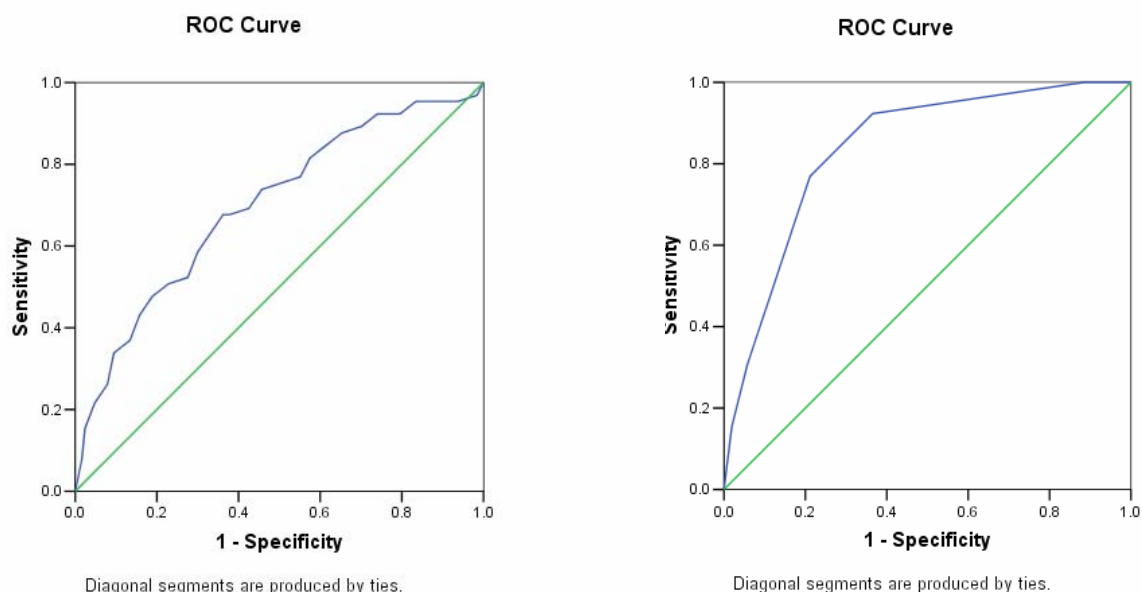


**Figure 9: ROC curve for the presence model indicating accuracy of predictions of Atlantic salmon. Sensitivity describes true positive rate and 1-Specificity false positive rate.**

Table 10 represents attributes of both models for odonates established from 228 quadrates sampled in the Souhegan River including 65 quadrates where these animals were found and 13 samples with more than 2 individuals. The presence model indicates affinity to glide habitat with fine gravel. The abundance model shows correlation with shaded deep areas with vegetative substrate. Figure 10 presents ROC curves for both models.

**Table 10: Physical attributes correlating with presence and high abundance of odonates. The Area Under ROC curve is a measure of the discrimination capacity of the model. Selected cut-off indicates the probability separating un-suitable, suitable and optimal habitats. ‘b’ represents regression coefficients of logistic regression model.**

<b>Odonates</b>			
<b>Presence Model</b>		<b>Abundance Model</b>	
Area under ROC curve	0.70	Area under ROC curve	0.84
Selected cut-off (Pt)	0.24	Selected cut-off (Pt)	0.23
<b>Variables in the Equation</b>	<b>b</b>	<b>Variables in the Equation</b>	<b>b</b>
Glide	2.298	Riprap	2.482
Microlithal	1.402	Canopy Shading	3.033
Average Froude	-0.357	Depth 100-125cm	23.698
Constant	-0.678	Phytal	13.831
		Constant	-6.351



**Figure 10: ROC curve for the presence model indicating accuracy of predictions of odonates. Sensitivity describes true positive rate and 1-Specificity false positive rate.**

Table 11 represents attributes of both models for mussels established from 228 quadrates sampled in the Souhegan River including 27 quadrates where these animals were found and no samples with more than 2 individuals. The presence model indicates affinity to fine substrate. Figure 11 presents ROC curves for both models

**Table 11: Physical attributes correlating with presence and high abundance of odonates. The Area Under ROC curve is a measure of the discrimination capacity of the model. Selected cut-off indicates the probability separating un-suitable, suitable and optimal habitats. ‘b’ represents regression coefficients of logistic regression model.**

<b>Mussels</b>	
<b>Presence Model</b>	
Area under ROC curve	0.82
Selected cut-off (Pt)	0.08
<b>Variables in the Equation</b>	<b>b</b>
Psammal	3.431
Microlithal	2.651
Constant	-3.355

## Spawning habitat

Our literature survey of the spawning requirements of GRAF and anadromous fish species allowed us to identify the habitat attributes and conditions (ranges of values) necessary to determine un-suitable, suitable, and optimal spawning habitat for these species. The seasonal timing, specific water temperature range, and strategies of spawning were also identified for each species but were not used as inputs in our spawning habitat suitability model. Table 12 presents the spawning habitat characteristics established for each species based on our literature survey.

Blacknose dace spawn in the spring to early summer of the year over fine gravel (akal) and gravel (microlithal) substrates when water temperatures are between 15 and 22 degrees Celsius (°C). They prefer fast flowing, shallow areas of riffle or glide habitats. Although nests are not constructed, and no parental care is given to the eggs, blacknose dace are known to spawn over the stone nests built by fallfish (Hartel et al., 2002).

Common shiner spawning occurs in the spring to mid-summer seasons when water temperatures are between 15 and 21°C. Upstream spawning migrations, prompted by water temperature typically begin in May. Spawning takes place in moderately shallow to shallow flowing water, riffle and glide habitats over sand (psammal) and gravel substrates. Eggs are deposited into natural depressions in the gravel, small depressions excavated by the males, or over the nests of other nest-building minnows such as fallfish (Hartel et al., 2002; Scarola, 1987).

Fallfish spawning occurs in the spring of the year when water temperatures are between 14 and 19°C. Spawning activity has been shown to cease as a result of fluctuations above or below this range in water temperatures during the spawning season (Ross and Reed, 1978). Instream migrations are made to suitable spawning locations consisting of gravel substrates, moderated to shallow depths, and slow current velocities in riffle, glide and pool habitats. The males of this species construct nests of gravel that are between 1-4 feet wide, and up to 2 feet high (Hartel et al., 2002; Scarola, 1987). It is believed that the act of nest building by males may initiate the spawning behavior in females of this species (Ross and Reed, 1978).

Longnose dace spawning occurs in the spring to early summer seasons when water temperatures are between 15 and 21°C. Spawning takes place in the fast moving, shallow water habitat of riffles, glides, and runs with gravel and cobble (mesolithal) substrates. Females are enticed to deposit their eggs between the crevices of rocks within a small (10" diameter) spawning territory guarded by the male of this species (Hartel et al, 2002; Scarola, 1987).

Slimy sculpin spawning occurs in the early spring when water temperatures are between 7 and 14°C. Spawning occurs in shallow, fast moving water of riffle habitats with gravel, cobble, or rocky (macrolithal) substrates. Females enter a crevice or cavity guarded by a male where they deposit their eggs on the underside of the substrate. Males guard the eggs and the young (Hartel et al., 2002).

White sucker spawning occurs in the early spring following upstream migrations to suitable areas when water temperatures are between 13 and 20°C. Eggs are broadcast in moderately

shallow to shallow flowing waters of riffle and glide habitats with gravel and cobble substrates (Hartel et al; Scarola, 1987).

American shad, an anadromous species make their annual spawning migration from the sea into freshwater rivers during the spring of the year when water temperatures are between 10 and 13°C (Hartel et al. 2002). Spawning occurs in moderate to deep-water runs, glides, and pools with swift to fast moving water. Spawning occurs between 8 and 26°C but is most frequent between 14 and 21°C (Stier, 1985)

Another anadromous species, Atlantic salmon spawn during the late autumn when water temperatures are between 4 and 10°C. At this time, adult Atlantic salmon that have spent the summer in coldwater pools of rivers or streams after making their spring upstream migration from the sea, move to suitable spawning areas in the upstream tributaries and portions of the river. Spawning habitat for this species consist of gravel (microlithal)-bedded riffles, runs, glides and sidearms with swift flowing, moderate to moderately shallow depths (Armstrong et al. 2003). Eggs and milt are deposited just upstream of a gravel nest (redd) which is constructed by the female by turning on her side and vigorously beating her tail to loosen the gravel. The eggs are protected within the redd where they incubate over the winter before hatching out in the spring (Scarola, 1987). The key attributes that could be used for habitat modeling are summarized in Table 12.

## Discussion

The models presented here all have a satisfying capacity to discriminate between occupied and not occupied habitats, which is indicated by high areas under ROC curves. The models also correspond well with empirical expectations. For example, all fluvial specialists show clear affinity towards fast flowing, riffle habitats. The habitat for fluvial dependent species such as white sucker and common shiner is characterized by swift but deeper areas. Brook trout habitat is diverse but also clearly associated with fast flowing areas. Bottom dwelling species such as slimy sculpin are associated with substrate accompanied by large interstitial areas: gravel and stones. Limited abundance of species such as common shiner and Atlantic salmon only allows for less precise models and the data was not sufficient to identify optimal habitats.

Because fish models are developed for individual species and on a very large database they are may be more reliable than those for invertebrates. On the other hand, lower mobility of invertebrate fauna reduces the impact of coincidence on the observations. The order of mussels and odonates occupies wide range of habitats and therefore the models presented here need to be considered inaccurate. However, we found only a few species in our samples with similar habitat use. Nevertheless, larger and more detailed sample would provide more precise criteria. Mussel habitat does not appear to be flow sensitive.

The literature based spawning model presented here is a more conservative and robust version of a previous model used to identify the level of suitability of habitats for spawning on the Quinebaug River. The previous model required that only a single measured value within a habitat unit meet the criteria of the attribute for that attribute to be considered suitable. The current model, requires that four out of the seven measured values for an attribute be met in order for the attribute to be considered as having met the criteria. The changes made to this

model seem to have strengthened it by requiring a greater portion of measured values to meet the criteria developed for each species in order to be considered suitable or optimal. This assures us that a more substantial area of the habitat possesses the defined attributes than in the previous model. Although these changes may cause decreases in the amount of suitable and optimal spawning habitat throughout the river due to its more conservative standards, our confidence in the accuracy of its ability to identify actual conditions of the habitat units is increased. Overall this model has an excellent ability to identify suitable spawning habitat for the selected species at various flows when applied to habitat mappings of the river conducted under multiple flow conditions.

**Table 12. Spawning habitat suitability criteria for the resident and anadromous fish species Souhegan River, New Hampshire**

<b>Target Fish Species</b>	<b>Seasonal Period</b>	<b>Water Temp.</b>	<b>HMU</b>	<b>Water Depth</b>	<b>Current Velocity</b>	<b>Choriotop (Substrate)</b>	<b>Comments</b>
Blacknose Dace	Early June through Mid-July	15-22.0°C	Riffles, Ruffles Glides	<20 cm	>45 cm/s	Akal, Microlithal	Small nest of pebbles/gravel
Common Shiner	May through Mid-July	15.5-21.0°C	Riffles, Glides	<50 cm	<40 cm/s	Psammal, Akal, Microlithal	Spawns over nests of other minnows
Fallfish	Late April through Early June	14.4-19.0°C	Pools, Riffles, Glides	<100 cm	<20 cm/s	Akal, Microlithal	Gravel nests built by male
Longnose Dace	May through Early July	15.5-21.0°C	Riffles, Ruffles, Runs, Glides	<15 cm	>45 cm/s	Microlithal, Mesolithal	No nest; male guards eggs
Slimy Sculpin	Late April through May	7-13.0°C	Riffles, Ruffles	<20 cm	>45 cm/s	Microlithal, Mesolithal, Macrolithal	Eggs deposited underside of rocks
White Sucker	Late April Through May	13.8-20.0°C	Riffles, Ruffles, Glides	<50 cm	15-55 cm/s	Akal, Microlithal, Mesolithal	Upstream spawning migrations

**Table 12 (continued). Spawning habitat suitability criteria for the resident and anadromous fish species Souhegan River, New Hampshire**

<b>Anadromous Fish Species</b>	<b>Seasonal Period</b>	<b>Water Temp.</b>	<b>Meso-Habitat</b>	<b>Water Depth</b>	<b>Current Velocity</b>	<b>Choriotop (Substrate)</b>	<b>Comments</b>
American Shad	May through Mid-June	Range: 8-26°C Peak: 14-21.0°C	Run, Glide, Pool, Fast Run	50-125 cm+	15-105	Psammal, Akal, Microlithal, Mesolithal	Depth/velocity Dependent
Atlantic Salmon	October through December	4.4-10.0°C	Riffle, Run, Glide, Ruffle, Rapid, Sidearm	25-75 cm	25-75	Microlithal	Substrate Dependent (Gravel)

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